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Intersection Delay--Signal Vs. Four-Way Stop

By Edward M. Hall (Jun. Mem., ITE)

Fig. 1
24th and Guerrero Streets—looking North.

Introduction

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Data concerning intersection delay should be useful in the proper selection of adequate traffic-control devices and in the determination of adequate warrants for their use. Existing warrants for signal control at intersections need further refinement and those for the use of two-way, three-way, and four-way-stop control need considerable development which can be achieved only with additional data.

The Traffic Engineering Handbook defines delay, fixed delay and operational delay. The delay studied in this research is included in those definitions but none delimits it. Consequently the term *control-device delay* has been coined. Control-device delay is that delay imposed upon through traffic at an intersection by the method of intersection control. Control-device delay varies with traffic volume on all approaches and with the interference within the intersection.

The purpose of this study was to compare the control-device delay of the average vehicle passing through an intersection that was first controlled by a four-way stop and later by semi-traffic-actuated signal equipment. Although nearly everyone has an opinion, sometimes violent, concerning the use of four-way-stop control, very few studies have been made of its operation. This study is the first to compare the four-way stop to semi-traffic-actuated signals in terms of delay. It is a limited study, concerning only one intersection and only one controller setting. This setting, as well as the physical installation, was that established for normal operation by the Traffic Engineering Division, Department of Public Works, City of San Francisco.

The intersection studied (see Figs. 1 and 2) was at 24th and Guerrero Streets, San Francisco. This is a simple 90-degree intersection of a heavily traveled four-lane divided arterial street (Guerrero Street), and a moderately traveled two-lane street (24th Street). It is in an intermediate urban area with moderate pedestrian volume. The average daily traffic (ADT) on Guerrero Street was 14,500 and on 24th Street, 5700—a volume split of approximately 70-30.

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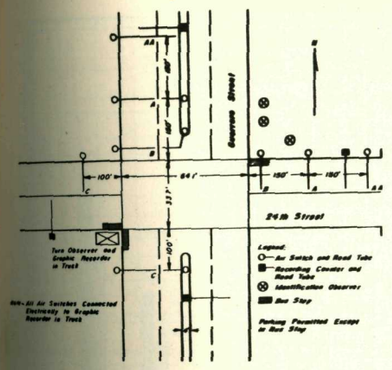

Fig. 2
Schematic diagram of equipment arrangement—24th and Guerrero Streets.

Procedure

The principal field effort was to record, by means of an Esterline-Angus 20 Pen Graphic Recorder, the "before and after" travel times of vehicles as they passed through a zone of influence at the studied intersection. Four other methods of measuring travel time were used for brief periods. The travel times obtained by the various methods were then compared to the travel times measured by the graphic recorder method.

The Esterline-Angus 20 Pen Graphic Recorder has 20 independent electrically operated pens. Each moves approximately ⅛ in. horizontally when the circuit to which it is individually connected is closed. The movement of the pen produces a pip on a chart which is driven at a selected constant speed by a clock motor. The chart speed selected for this study was such that the smallest division on the chart equalled one second. Various means may be used to close the circuits to operate the pens. In this study some circuits were closed by road-tube air-switch actuation by a vehicle crossing the road tubes; others were closed by keys operated by the observers.

Two right-angle approaches to the intersection were studied. It would have been desirable to study all four approaches but manpower was limited. It is important to consider that both the field installation time and the time to extract the data from the graphic recorder tapes would have been approximately doubled if all four approaches had been studied. The use of only two approaches to an intersection has been found to give accurate results in a study of various types of controllers being conducted by the Institute of Transportation and Traffic Engineering.

Road tubes were placed at three locations on each lane on each of the two studied approaches: before the intersection, at the stop line, and beyond the intersection (Fig. 2). Both the longitudinal and transverse location of the road tubes are important considerations. Each road tube was connected to an air switch which was electrically connected to the graphic recorder. Observers were assigned to various positions from which they recorded such items as identity of vehicles passing through the section, turning movements, and parking; this information was recorded by operating keys connected electrically to the graphic recorder. Each traveled lane was individually investigated. Four inexperienced men installed the necessary equipment in 5 hours; four experienced men, in 2 hours.

All the data was recorded on the graphic recorder tapes. This has the advantage of permitting permanent and accurate recording of several items of information. The overall travel time through the studied section was the only data extracted from the tapes for this study. The proper design of the pen code is of considerable importance both in field inspection of recorder operation and in subsequent extraction of data. Even with a well designed code, however, extraction of data is a time-consuming task. In this study, approximately 17⅓ man-hours were required for a four-man crew to collect and extract 1 hour of data, 12 of the 17⅓ man-hours being consumed on location.

A test of the use of IBM tabulating cards and machines to reduce the time required to extract and analyze the data from the tapes was made possible through the cooperation of Mr. Sam Osofsky, California Division of Highways. Data on two tapes was first extracted and analyzed by hand and then extracted directly from the tapes onto cards and analyzed mechanically. The hand method required 19.4% fewer man-hours than the mechanical method.

The Findings

The average travel times were almost exactly the same for both the inside and the outside lanes on Guerrero Street during the peak and off-peak periods. Since this similarity of lane travel existed in the 15-minute periods, as well as the peak and off-peak periods, the travel times were averaged by approach, regardless of the number of lanes. The volumes were generally higher in the inside lane.

It is reasonable to assume that a driver desires to proceed from one point to another at some constant speed. If there were no intersections, it might be possible to approach this optimum condition. Optimum overall travel times through the studied sections, Tube "A" to Tube "C", were obtained by test car observations and theoretical computations. The optimum travel times were subtracted from the average measured travel times to determine the average control-

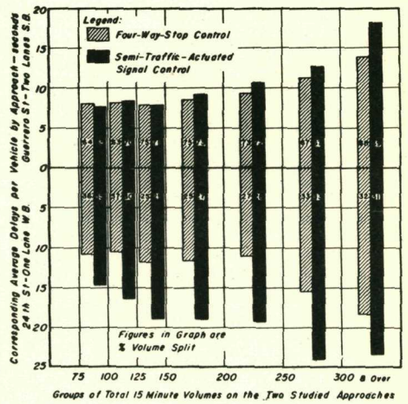

Fig. 3
Corresponding average control-device delay vehicle by approach vs. total volume on the two approaches—24th and Guerrero Streets.

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device delays of both types of control which were then compared. The same relative results would be obtained by merely comparing the average measured travel times under the two types of control.

The data was analyzed by 15-minute periods. The total volumes passing through the intersection on the two studied approaches in the 15-minute periods were then grouped. These groups were relatively small and designed to equalize the number of 15-minute samples in each. The average of all 15-minute average control-device delays, on each approach, in each volume group were then determined.

Figure 3 shows the corresponding average control-device delay for each vehicle by its approach to the intersection against the total 15-minute volume passing through the intersection on the two studied approaches. The average volume split of each of the two studied approaches is given for both types of control. It is interesting to note that these volume splits are very similar except in the volume group 100-124, where the difference is only 7%. Figure 3 reveals that the control-device delay is significantly increased on the minor street for all volumes, and on the major street for volumes above 800 vehicles per hour (200 per 15 minutes) by changing from four-way-stop to semi-traffic-actuated control.

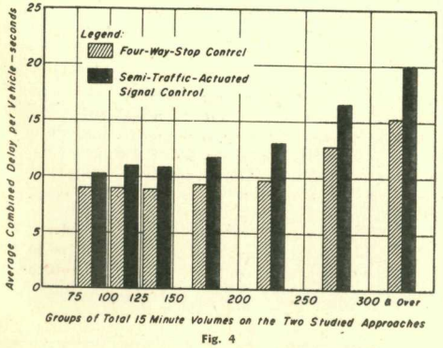

Fig. 4

Average combined control-device delay per vehicle for both approaches vs. total volume on the two approaches—24th and Guerrero Streets.

Figure 4 shows the average combined control-device delay per vehicle approaching on the two studied legs in the appropriate volume groups. The average combined control-device delay per vehicle is greater with semi-traffic-actuated signal control than with four-way-stop control for all volumes studied. The differences between the control-device delays of signal and stop control increase as the volumes increase through the range of studied volumes.

The average total vehicle minutes of control-device delay for all vehicles on the two right-angle approaches is plotted by volume group in Figure 5. The total control-device delay with signal control was greater than with four-way-stop control for all volumes studied. The differences in the total control-device delays increased as the volume increased through the volume ranges studied.

The results of this study as shown in Figures 3-5 may be logically explained by considering that an intersection controlled by a four-way stop generally has at least one vehicle in it. This means that from the delay standpoint efficient use is being made of the intersection. A signal by its very nature is relatively inefficient from the standpoint of maximum use of the intersection, at least in the volumes studied here. This is one of the reasons for the growing use of actuated signal equipment.

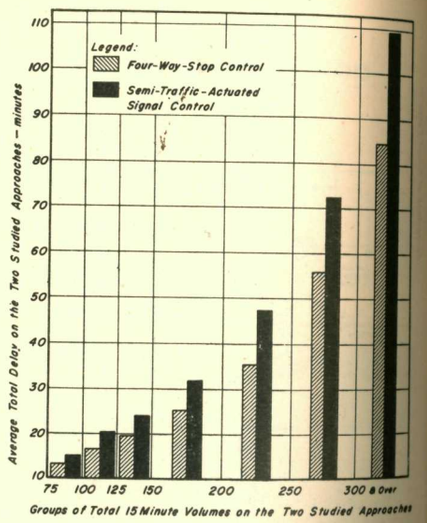

Fig. 5

Average total control—device delay for all vehicles for both approaches vs. total volume on the two approaches—24th and Guerrero Streets.

Figures 6-9 show the frequency distributions of the travel times from Tube "A" to Tube "C" under both types of control. More vehicles passed through the intersection with low travel times under signal control than with four-way-stop control. However, some vehicles were delayed for much longer times with signal control and therefore the average values of control-device delay are generally lower with four-way-stop control.

The patterns of the distribution are distinct for peak and off-peak times and for each type of control. The range in travel times is considerably less with stop control. The graph of stop control has one generally sharp mode and approaches a "normal" distribution while that of signal control has one very sharp, early mode followed shortly by a second smaller mode and considerably later by a third distinct mode of some magnitude. The three peaks of the signal control travel time distribution graphs are probably formed by vehicles that (1) go through the intersection with no delay, (2) are slowed

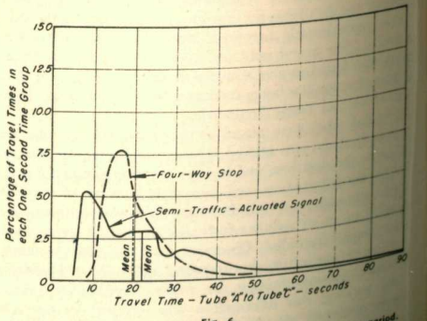

Fig. 6

Distribution of travel times—Guerrero Street peak 1½ hour period.

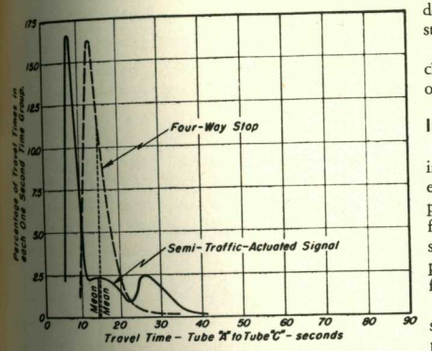

Fig. 7

Distribution of travel times—Guerrero Street off-peak 2 hour period.

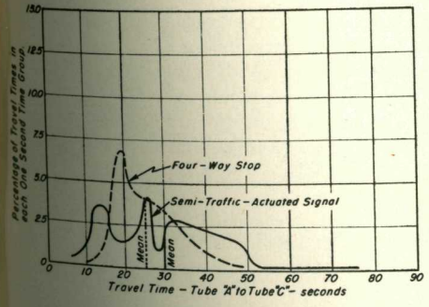

Fig. 8

Distribution of travel times—24th Street peak 1½ hour period.

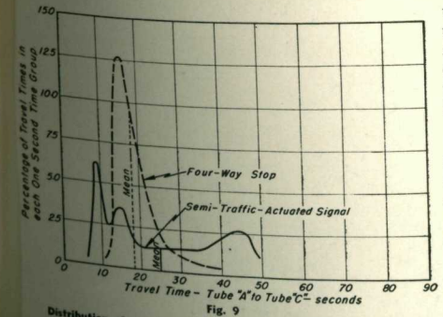

Fig. 9

Distribution of travel times—24th Street off-peak 2 hour period.

down or are briefly stopped by the signal, and (3) are stopped and held by the signal.

These graphs may be closely associated with driver psychology and may well explain driver acceptance and rejection of various control devices.

Interpretation and Application

This study pertains only to control-device delay. In forming certain conclusions from the data of this study, it is emphasized that only one phase of a multiphase problem is presented. On the other hand, delay is such a significant factor that the use of delay as one measure of overall intersection operating efficiency seems justified. Further, there is probably a relation between delay and each of the other factors involved in an intersection study.

Some of the other factors that may be considered in a study of the efficiency of an intersection are accidents; driver preferences; costs of installation and operation of the control devices; vehicle operating costs; effects on pedestrians; and physical conditions.

A study of driver preferences might include such questions as:

1. Do motorists prefer a relatively short delay at each controlled intersection or a longer delay at some of the controlled intersections?
2. Do motorists prefer to accept a greater delay if the right-of-way is automatically assigned to them periodically?
3. Should the words "Four-Way" be added to stop signs at intersections using four-way stop control?

One rather significant point should be made concerning the "back-up" of vehicles. Under four-way-stop control there was some "back-up", but it did not extend over Tube "A", except once briefly during the peak. There was considerable "back-up" on both streets with semi-traffic-actuated signal control. This is important because a vehicle in a "back-up" behind Tube "A" is certainly being delayed, yet this delay is not being recorded directly. Indirectly it shows up as an overall relatively longer travel time due to a slower approach speed at Tube "A".

From this it can be concluded that the type of control with the most "back-up" over Tube "A" will appear somewhat more efficient, from the standpoint of control-device delay, than it actually is. Semi-traffic-actuated signal control will therefore cause relatively more control-device delay with respect to four-way-stop-control than is shown in Figures 3-5.

The *Highway Capacity Manual* gives no values for capacities of intersections controlled by four-way-stop or vehicle-actuated signals. If delay is a major criterion of capacity for the two types of intersection control studied in this research, the results would indicate that perhaps the capacity of an intersection under four-way-stop control is greater than the capacity under semi-traffic-actuated signal control in the volume ranges studied here. This important subject deserves further study.

Consideration should be given to the fact that prior to installation of the semi-traffic-actuated signal control at 24th and Guerrero Streets, and five other nearby intersections, there was an extensive system of four-way-stop control in the area. It is possible that drivers in the area became conditioned to four-way-stop control and therefore proficient in driving under such control.

A general observation of the flow of traffic through the intersection gave the impression of amazing smoothness under four-way-stop control.

On the basis of the facts obtained in this study, plus a

few assumptions, it is possible to estimate the cost of the increased delay experienced at this intersection after the installation of semi-traffic-actuated signal control. Assuming the time of an average driver to be worth $1.00 per hour the total value of the increased time loss would be something like $3300 per year. The savings in vehicle operating costs, if any, would have to be subtracted from the value of the time loss to determine the net loss or gain to the motoring public.

The cost of installing semi-traffic-actuated signal control was approximately $4800. The approximate cost of installing four-way-stop control is $50.

But psychological values may be involved too. For example, motorists may prefer the certainty of right-of-way obtainable with signal control.

Conclusions

At the intersection of 24th and Guerrero Streets, San Francisco, the patterns of the frequency distributions of the travel times were distinct for peak and off-peak periods and for each type of control. The travel time distribution graphs may indicate one reason why some drivers prefer signal to four-way-stop control even though the average delay of the signal may be greater.

The average control-device delay per vehicle on 24th Street, the minor street, was significantly greater with semi-traffic-actuated signal control than with four-way-stop control for all studied volumes. The average delay per vehicle on Guerrero Street, the major street, was significantly greater with signal control for all volumes above 800 vehicles per hour on the studied approaches. However, many factors were not investigated and, therefore, no conclusion can be drawn as to which type of control would be preferable, and no such conclusion is inferred.

It is hoped that these findings may present a challenge to others to obtain more data on this subject. Such data are badly needed for the proper selection of traffic-control devices and for the refinement of warrants concerning their use.

PRESS OF INTERSTATE

1952
PROCEEDINGS

Institute of Traffic Engineers

TWENTY-THIRD ANNUAL MEETING

Held at
Hotel Sherman, Chicago, Illinois
September 8-11, 1952

Headquarters
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